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Case Study

Mapping and assessment of ecosystem services at Troodos National Forest Park in Cyprus

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Abstract

Troodos National Forest Park is located in the centre of Troodos mountain range and it is one of the most important natural environments of Cyprus. It has been included to the Natura 2000 network of the Island due to its important natural ecosystems and its great biodiversity. Based on the Common International Classification of Ecosystem Services (CICES 5.1), 36 ecosystem services have been identified in the area. The majority of ecosystem services are concentrated at the Troodos peak and the nearby areas. The same pattern applies for the Cultural Services. Provisioning and Regulation-Maintenance services are concentrated at the centre and western part of the site. The site's habitat types were mapped and their distribution in the area is presented in respective maps. Carbon stored in plants was 622,705 tonnes in total (73.18 t C per ha), calculated as per habitat type (according to Directive 92/43/EEC - Habitats Directive) and as per TESSA habitat classification. Seven TESSA and 10 Annex I habitat types were identified. The largest part of the site is dominated by Evergreen Broadleaf Forests (7799 ha), followed by Mixed Forests (624 ha) and Deciduous Broadleaf Forests (60 ha). The carbon stock included in AGB (Above Ground Biomass), BGB (Below Ground Biomass), Dead Wood & Litter and SOM (Soil Organic Matter) was evaluated for each habitat type. The annual carbon biomass removal (roundwood and fuelwood) is 80.82 t C y^{-1} (0.009 t C y^{-1} per ha), while the carbon sequestered in Troodos National Forest Park is 11,880.33 t CO_2 eq y^{-1} (0.38 t C y^{-1} per ha). The information produced serves as a useful tool to competent

authorities for raising awareness on the importance of ecosystem services and increase the public's support in the area's conservation.

Keywords

carbon storage, Cyprus, ecosystem services, protected area, Troodos

Introduction

Ecosystems provide a multitude of benefits to humanity, from food, clean water and flood protection to cultural heritage and a sense of place (Science for Environment Policy 2015). These benefits are called 'ecosystem services' (ESs). The concept of ESs was brought into widespread use by the Millennium Ecosystem Assessment (MA), a global initiative set up in 1999 to assess how ecosystem change would affect human well-being (Corvalan et al. 2005). In Europe, following the Biodiversity Strategy to 2020, the Mapping and Assessment of Ecosystems and their Services (MAES) initiative was set up and produced a framework for ecosystem assessment, to ensure a harmonised approach across the European Union (EU) (Maes et al. 2013). Nowadays, ESs are distinguished in three categories, following the Common International Classification of Ecosystem Services (CICES):

1. Provisioning services;
2. Regulating and maintenance services and
3. Cultural services (Haines-Young and Potschin 2013).

Despite the importance of ESs to people, many have been taken for granted in the past, being viewed as free and infinite. It is now clear that the worldwide degradation of ecosystems is also reducing the services they can provide. However, healthy ecosystems are the fundamental basis for a resilient society and a sustainable economy. Healthy soils underpin forestry and agricultural production and income of landowners. Apart from direct economic benefits, healthy forests are essential providers of many regulating ecosystem services. Healthy rivers and lakes provide abundant clean water, are habitats for fish and wildlife and provide recreation opportunities (Maes et al. 2018).

Currently, many of these benefits provided by ecosystems are under severe threat from anthropogenic pressures. A recent report on the conservation status of habitats and the chemical and ecological status of water bodies (Maes et al. 2020), analysed the trends in ecosystem services and concluded that the current potential of ecosystems to protect against floods, provide timber, crop pollination and nature-based recreation is equal to or lower than the baseline value for 2010. The decrease in ESs potential at EU level was attributed to land cover changes, along with the deterioration on the condition of most ecosystems. More data need to be collected by countries to improve knowledge gaps (Díaz et al. 2019), in order to fulfil the international and EU obligations and contribute to the assessment of ESs (including Cyprus).

Only few papers and works are available in the international literature about ESs services provided by Cyprus' ecosystems. Cyprus is still at an early stage of quantifying the services offered by its ecosystems. In a relatively recent study (Vogiatzakis et al. 2017), the general categories of ecosystems that exist on the Island were determined and the services provided by these ecosystems were identified (based on their CICES classification). The relevant indicators were also proposed for the quantification of ecosystem services. In the same study, selected ecosystem services (i.e. main ecosystems in Cyprus, crops and wetlands) were mapped, based on data availability. However, the data used were for 2012 and are not considered representative in the year of completion of the study.

More systematic efforts for mapping/evaluation of ecosystem services have been made for four sites included in the Natura 2000 network: Rizoelia National Forest Park - CY6000006 (Manolaki and Vogiatzakis 2017), Larnaca Salt Lake - CY6000002 and Oroklini Lake CY6000011 (Department of Environment 2018) and Koshi-Pallourokampos site (Kounnamas et al. 2017), as well as for Cyprus river ecosystems (Vogiatzakis et al. 2018). All efforts concern ESs provided by water resources, except the mapping of services at Rizoelia National Forest Park and Koshi-Pallourokampos site, which are both peri-urban forested areas, mainly with non-native vegetation.

This study aims to improve the available knowledge on ESs provided by Cyprus ecosystems, in a mountainous natural area, i.e. Troodos National Forest Park (TNFP). More specifically, it presents in detail the ESs mapped in this area and assesses the Global Climate Regulation (GCR) (including carbon storage) for TNFP.

Methodology

Study area

Troodos National Forest Park (Fig. 1) is located in the heart of Troodos mountain range and was designated as a National Forest Park in 1992, aiming to safeguard its sustainable use and to perpetuate its natural values and functions of the area. The Park (with an area of 90 km^2) constitutes the most important forest ecosystem of the Island and its largest part has been included in the Natura 2000 network (CY5000004) since 2004. Troodos National Forest Park hosts the highest number of indigenous and endemic plant taxa from any other area of Cyprus, belonging to one of the ten hotspots of the Mediterranean Basin, based on plant endemism and richness (Medail and Quezel 1997). It hosts more than 750 plant taxa, i.e. 40% of the total flora of Cyprus, 70 of which are endemic to Cyprus (50% of the endemics of Cyprus). Ten taxa are local endemics, found only at TNFP and nowhere else in the world. Troodos National Forest Park also hosts 21 threatened taxa (IUCN list) (Hand et al. 2019).

Mapping of Ecosystem Services

The mapping of the ESs used the CICES 5.1 method (Haines-Young and Potschin 2018) and was carried out by a team of experts (two conservation biologists, a forester, a systematic biologist and an ecologist) and personnel working in the area (two foresters working for the Department of Forests). The assessment was carried out in one session, where the participants, based on their experience (all participants were well acquainted with the area), evaluated the occurrence of each ES in TNFP, using 1 km x 1 km grid over a raster image of the TNFP. The grid was created using the software ArcMap (v. 10.7.1 of ESRI, USA). For each ES identified in each grid, a score was given, based on a 5-scale grading system, ranging from 1 (least importance) to 5 (highest importance). The average score from the participants was recorded in a matrix (see Suppl. material 2). The total score of each ES and ESs category was utilised to prepare respective maps (a 10-colour grading, from lighter to darker colours, representing lower to higher scores). Specifically, ArcMap software was used to create four vector maps, one for each ESs category and one for all the categories combined, as well as maps for each ES (Suppl. material 3).

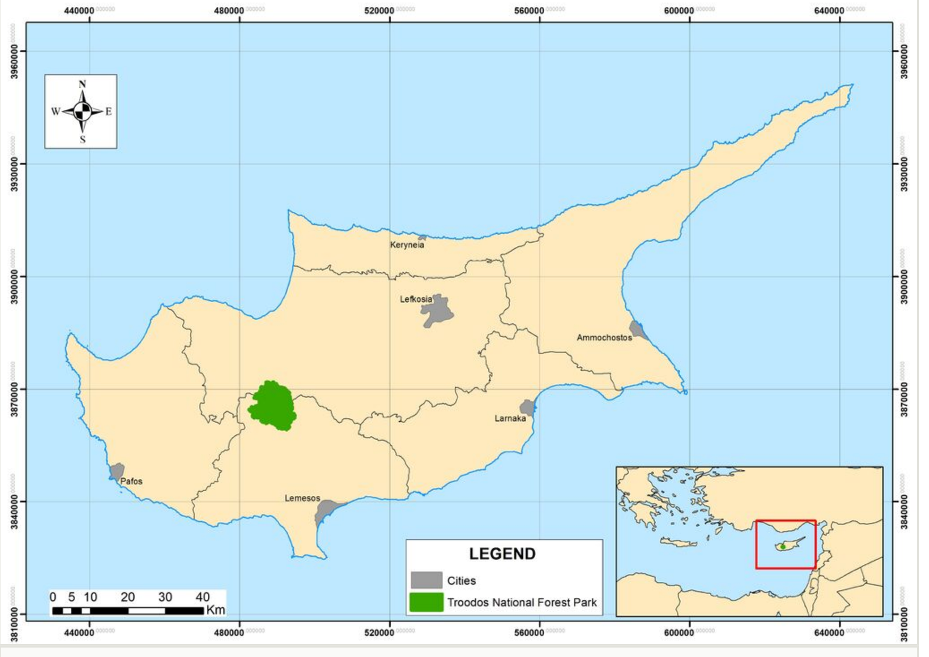

Figure 1.

Study area of Troodos National Forest Park.

In order to assess the GCR (including carbon storage) for the TNFP, the most recent available habitat mapping of the TNFP (provided by the competent authority, the Department of Forests), the TESSA (Peh et al. 2017) toolkit and the methods/tools provided therein, were utilised. The data required for the assessment were obtained from the databases of the DF and field surveys (i.e. information relating to the use of the area).

The factors considered for the GCR were:

1. The carbon stored in the plants [i.e. Above-Ground Biomass (AGB) and Below-Ground Biomass (BGB)], dead organic matter (litter and dead wood) and soil.

2. The greenhouse gases [carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4)] emitted by the plants, soil and animals over time (positive flux). These emissions can arise from, for example, respiration, burning, decay or other forms of disturbance.
3. The carbon sequestered (taken in from the atmosphere) over time by the plants and soil (negative flux), expressed as annual change in carbon stocks in biomass.

Carbon stored in plants

The carbon stored in the plants derives by summing its four constituents: AGB, BGB, dead organic matter and Soil Organic Matter (SOM).

Above-Ground Biomass was assessed using TESSA's Climate Method (CM) 2 (Peh et al. 2017) and IPCC tier 1 estimates (Eggleston et al. 2006, Buendia et al. 2019). Carbon (in tonnes) was estimated using the available file at TESSA toolkit "*Estimated values of biomass and soil organic matter of various habitat types*", in addition to IPCC Table 4.7. The ecological zone is “Subtropical dry forest”, according to the Forest Resources Assessment (2015). AGB was estimated for five habitat cases (based on the habitats mapped in TNFP according to TESSA habitat classification):

(1) AGB_{CSL} = total area of habitat (ha) x 48 x 0.5

(2) AGB_{OSL} = total area of habitat (ha) x 70.9 x 0.5

(3) AGB_{GR} = total area of habitat (ha) x 2.3 x 0.47

(4) AGB_{WET} = total area of habitat (ha) x 15 x 0.47

(5) AGB_{TDH} = total area of habitat (ha) x 70.9 x 0.5

(6) $AGB_{TOTAL} = AGB_{CSL} + AGB_{OSL} + AGB_{GR} + AGB_{WET} + AGB_{TDH}$

Where:

a) CSL = Closed Shrublands, OSL = Open Shrublands, GR = Grassland, WET = Seasonal/ intermittent freshwater lakes, TDH = Tree-Dominated Habitats (evergreen or deciduous broadleaf/needleleaf and mixed forests).

b) IPCC tier 1 estimates of Above Ground Live Biomass = 48 for CSL, 2.3 for GR, 15 for WET and 70.9 for OSL and TDH.

c) 0.5 = Conversion factor for tree-dominated habitats and Closed/Open Shrublands.

d) 0.47 = Conversion factor for Grassland habitats and wetlands.

Below-Ground Biomass was assessed using TESSA's CM 5, while Carbon was estimated using the available file "Estimated values of biomass and soil organic matter of various habitat types", in addition to IPCC Table 4.4 (use of BGB/AGB ratio) (Eggleston et al. 2006, Buendia et al. 2019). Below-Ground Biomass was estimated for six habitat cases:

(7) BGB_{CSL} = total area of habitat (ha) x 48 x 0.5

(8) BGB_{OSL} = total area of habitat (ha) x (0.44 x AGB_{OSL}) x 0.5

(9) BGB_{GR} = total area of habitat (ha) x 14 x 0.47

(10) BGB_{WET} = total area of habitat (ha) x 19 x 0.47

(11) BGB_{ETDH} = total area of habitat (ha) x (0.44 x AGB_{ETDH}) x 0.5

(12) BGB_{BTDH} = total area of habitat (ha) x (0.44 x AGB_{BTDH}) x 0.5

(13) $BGB_{TOTAL} = BGB_{CSL} + BGB_{OSL} + BGB_{GR} + BGB_{WET} + BGB_{ETDH} + BGB_{BTDH}$

Where:

a) CSL = Closed Shrublands, OSL = Open Shrublands, GR = Grassland, WET = Seasonal/ intermittent freshwater lakes, ETDH = Tree-Dominated Habitats (Needleaf forests), BTDH = Tree-Dominated Habitats (Broadleaf forests).

b) The ratio of BGB to AGB for OSL, BTDH and ETDH is 0.44, which is multiplied with the respective AGB.

c) IPCC tier 1 estimates of Below Ground Biomass = 48 for CSL, 14 for GR, 19 for WET.

d) 0.5 = Conversion factor for tree-dominated habitats and Closed/Open Shrublands.

e) 0.47 = Conversion factor for Grassland habitats and wetlands.

Litter and dead wood were assessed using TESSA's CM 6. For Litter, Carbon was estimated using the available file "*Estimated values of biomass and soil organic matter of various habitat types*", while for dead wood, IPCC's Table 2.2 (Buendia et al. 2019) was used (with values for the "Subtropical mountain system" zone).

The carbon for dead wood is estimated as follows:

(14) C_{DW} = 11.8 x total area of habitat (ha) x 0.5

Where:

a) 11.8 = IPCC tier 1 estimates of dead wood.

b) 0.5 = Conversion factor for dead wood.

The carbon for litter is estimated as follows:

(15) C_{CSL} = 6 x total area of habitat (ha) x 0.4

(16) C_{WET} = 25 x total area of habitat (ha) x 0.4

(17) $C_{LIT} = C_{CSL} + C_{WET}$

Where:

a) WET = Seasonal/intermittent freshwater lakes, CSL = Closed Shrublands [the litter from the Grasslands is negligible, while no TESSA/IPCC Tier 1 information is available for Tree-Dominated Habitats (Broadleaf or Needleaf forests) and Open Shrublands].

Soil organic matter was assessed using TESSA's CM 7, based on the available data on soil composition and respective habitats (see Fig. 2), which showed that all habitats occur on High Activity Clay soils (HAC soils consisting of Cambisols, Regosols, Leptosols – mineral soils), whilst the area has warm temperate dry climate (IPCC's Volume 4, Chapter 3, Appendix 3A.5 from Eggleston et al. 2006). Additionally, IPCC's tables 2.3 and 5.2 where used (Hiraishi et al. 2014). SOM was estimated for the following cases:

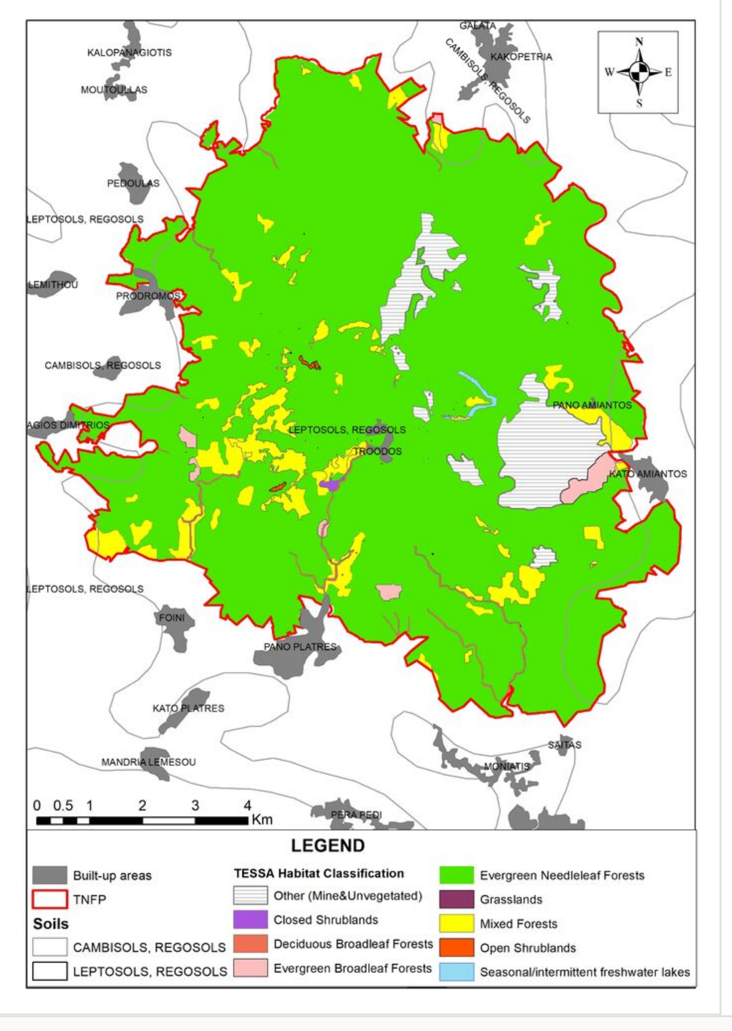

Figure 2.

TESSA habitat classification at Troodos National Forest Park.

(18) $SOM_{REF\ T}$ = 24 x total area of habitat (ha).

(19) $SOM_{REF\ W}$ = 74 x total area of habitat (ha).

(20) $SOM_{REF} = SOM_{REF\ T} + SOM_{REF\ W}$

Where:

a) $SOM_{REF\ T}$ = 24 for HAC soils at tree-dominated (natural or managed) and grass-dominated (natural) habitats.

b) $SOM_{REF\ W}$ = 74 for HAC soils at wetlands.

The Total Carbon is calculated with the addition of all above in tonnes (t), i.e.

(21) $C_{TOTAL} = AGB_{TOTAL} + BGB_{TOTAL} + C_{DW} + C_{LIT} + SOM_{REF}$

Methane emissions assessment

The assessment was done using TESSA's CM 11 and Table 3A.2 in Appendix 3 of IPCC (Eggleston et al. 2006). Methane emissions were estimated using the following:

(22) CH_4 Wet Soils = (P x $E(CH_4)$diff x $A_{flooded}$) / 1000

Where:

a) P = Ice-free period (where the total days in a year are 365).

b) $E(CH_4)$diff = Conversion factor of emissions at the area (factor of 0.044 - median, at an area with warm temperate dry climate).

c) $A_{flooded}$ = area in ha.

The carbon lost as methane is then calculated by multiplying the above resulting value by 0.75.

Annual gain in biomass

The change was estimated using the methods described in Chapters 2 and 4 of IPCC (Eggleston et al. 2006), along with the related tables 4.3, 4.4 [updated with data from Buendia et al. (2019)] and 4.5, that included the estimation of the annual biomass gain in Forest Land (ΔC_G) using estimates of area and biomass growth, with available data for each forest type.

The annual increase in carbon stocks due to biomass growth (ΔC_G), was estimated as follows:

(23) $\Delta C_{G\text{-}BR}$ = A x CF x $G_{TOTAL\text{-}BR}$ = A x 0.48 x 2.189 (or 0.231 for *Quercus* spp.)

(24) $\Delta C_{G\text{-}CON}$ = A x CF x $G_{TOTAL\text{-}GR}$ = A x 0.51 x 0.697

(25) $\Delta C_G = \Delta C_{G\text{-}BR} + \Delta C_{G\text{-}CON}$

Where:

a) A = area of land (ha).

b) CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$. The CF was 0.48 for broadleaves and 0.51 for conifers.

c) G_{TOTAL}= mean annual biomass growth (tonnes d.m. ha^{-1} y^{-1}). This was estimated following the Tier 2 method as follows:

i) For broadleaves: $G_{TOTAL} = I_V \times BCEF_I \times (1+ R) = 2 \times 0.55 \times (1+0.44) = 1.584$. For habitats with *Quercus* spp. $G_{TOTAL} = 0.2 \times 0.55 \times (1+0.44) = 0.1584$.

ii) For conifers: $G_{TOTAL} = I_V \times BCEF_I \times (1+ R) = 1.2 \times 0.45 \times (1+0.44) = 0.7776$.

Where:

- R = ratio of BGB to AGB for a specific vegetation type, in tonne d.m. BGB (tonne d.m. AGB)$^{-1}$. R is set to zero for no changes of BGB allocation patterns (Tier 1).
- I_V = average net annual increment for specific vegetation type, m^3 ha^{-1} y^{-1}. The value used for broadleaves is the same as the default value used in the National Inventory Report, which is 2 m^3 ha^{-1} y^{-1}, where also harvesting was assumed to be constant (Menelaou and Christodoulou 2019). The value for the conifers (ha^{-1} y^{-1}) was determined, based on the results of Forest Inventories, made in the *Pinus brutia* plots in the State Forest (1991-1992, 2001-2002 and 2011-2012), by the DF and was found to be 1.2 m^3 ha^{-1} y^{-1} (2018 data). The respective value for the *Quercus alnifolia* habitat was found to be 0.2 m^3 ha^{-1} y^{-1} [based on expert judgement from the DF and according to the Management Plan of Paphos Forest (Gatzogiannis et al. 2010].
- BCEF = biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to above-ground biomass growth (m^3 net annual increment)$^{-1}$.

Above-ground biomass loss

Loss in biomass carbon stocks was assessed using TESSA's CM 8 and Tables 4.3 and 4.5 of Chapter 4 of IPCC (Eggleston et al. 2006). The annual decrease in carbon stocks due to biomass loss (ΔC_L) adds the annual carbon loss in biomass of wood removals ($L_{WOOD\text{-}REMOVALS}$), fuelwood removals ($L_{FUELWOOD}$) and due to disturbance ($L_{DISTURBANCE}$) (which in the area equals to 0 t C y^{-1}) (i.e. $\Delta C_L = L_{WOOD\text{-}REMOVALS} + L_{FUELWOOD} + L_{DISTURBANCE}$).

$L_{WOOD\text{-}REMOVALS}$ (in t C y^{-1}) was estimated as follows:

(26) $L_{WOOD\text{-}REMOVALS} = H \times BCEF_R \times CF$

$L_{FUELWOOD}$ (in t C y^{-1}) was estimated as follows:

(27) $L_{FUELWOOD} = FG \times BCEF_R \times CF$

Where

a) H = Annual roundwood removals (in m^3 y^{-1}).

b) CF = Default value of the carbon fraction of dry matter [value for the area 0.47 t C for all tree types (t dry mass)$^{-1}$].

c) $BCEF_R$ = Default value of biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark) [value for the area 0.67 (m^3 of removals)$^{-1}$].

d) FG = annual fuelwood and charcoal removals (in m^3 y^{-1}) (data provided by the DF for year 2017).

Annual change in carbon stocks in biomass

The annual change in carbon stocks in biomass (ΔC_B in t C y^{-1}) was assessed using Chapter 2 of IPCC (Eggleston et al. 2006), with the formula: $\Delta C_B = \Delta C_G - \Delta C_L$ (Equation 2.7), where the values for ΔC_G and ΔC_L are estimated as presented above.

Global Warming Potential

Three greenhouse gases that affect climate, namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are converted into CO_2 equivalents (CO_2Eq) so that they can be directly compared and the region's net greenhouse gas flow can be calculated. The Overall Greenhouse Gas flux was assessed using TESSA's CM 14.

Each atom of carbon sequestrated represents a CO_2 molecule removed from the atmosphere. The carbon calculated on the basis of CM 7 (t C y^{-1}) for SOM, is expressed in CO_2 (t CO_2 y^{-1}) by multiplying with 44/12 (molecular weight of C and O is 12 and 16, respectively). Troodos National Forest Park had no organic soils for carrying out the corresponding calculation as per CM 9.

The Global Warming Potential (GWP) is "*an index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon, relative to that of the reference substance, carbon dioxide (CO_2)*" (Pachauri and Meyer 2014). Global Warming Potential, calculated at the centennial level (GWP_{100}) is used in this study, where, for CO_2, CH_4 and N_2O, the values are 1, 28 and 265, respectively (climate-carbon feedback was not taken into account).

Results

The ES mapped in TNFP belong to all three main categories. Specifically, there are 12 provision services, 12 regulating and maintenance services and 11 cultural services. These

ES belong to five sections, eight divisions, 22 groups and 36 classes. The identified ES are presented as an appendix (see Suppl. material 1).

Seven TESSA habitats (Open Shrublands, Closed Shrublands, Deciduous Broadleaf Forests, Evergreen Broadleaf Forests, Grasslands, Mixed Forests, Seasonal/intermittent freshwater lakes) and 10 Annex I (Habitats Directive) habitat types (5210, 5330, 92C0, 9390*, 9540, 9536*, 9560*, 8140, 62B0*, 6460) were identified within TNFP and presented in Fig. 2 and Fig. 3, respectively. The correlation between TESSA habitats and Annex I (Habitats Directive) can be found in Table 1.

Table 1.

Carbon stored in plants per habitat type (classification as per Habitats Directive 92/43/EC) and per TESSA habitat classification. CY03 refers to a Cypriot habitat type, i.e. Chasmophytic communities of water-sprayed or water flushed rocks (Adiantetea).

Habitat type	TESSA habitat classification	Area (ha)	AGB (tonnes C)	BGB (tonnes C)	DEAD WOOD & LITTER (tonnes C)	SOM (tonnes C)	CARBON (tonnes C)	CARBON PER HA (t ha^{-1})
5210	Open Shrublands	5.28	187.18	41.18	31.15	126.72	386.23	73.15
5330	Closed Shrublands	6.36	152.64	152.64	15.26	152.64	473.18	74.4
92C0	Deciduous Broadleaf Forests	60.41	2,141.53	471.14	356.42	1,449.84	4,418.93	73.15
9390*†	Evergreen Broadleaf Forests	140.52	4,981.43	1,095.91	829.07	3,372.48	570,468.58	73.15
9540		3,316.62	117,574.18	25,866.32	19,568.06	79,598.88		
9536*		4,239.48	150,289.57	33,063.71	25,012.93	101,747.52		
9560*		102.1	3,619.45	796.28	602.39	2,450.40		
8140	Grasslands	0.25	0.27	1.65	0	6	43.7	31.67
62B0*		0.63	0.68	4.15	0	15.12		
CY03		0.5	0.54	3.29	0	12		
5210+9540	Mixed Forests	2.08	73.74	16.22	12.27	49.92	45,617.94	73.15
9390*+5420		8.04	285.02	62.7	47.44	192.96		
9390*+9536*		33.53	1,188.64	261.5	197.83	804.72		
9390*+9560*		20.86	739.49	162.69	123.07	500.64		

Habitat type	TESSA habitat classification	Area (ha)	AGB (tonnes C)	BGB (tonnes C)	DEAD WOOD & LITTER (tonnes C)	SOM (tonnes C)	CARBON (tonnes C)	CARBON PER HA (t ha^{-1})
9536*+9560*		12.85	455.53	100.22	75.82	308.4		
9540+5210		0.03	1.06	0.23	0.18	0.72		
9540+9390*		367.53	13,028.94	2,866.37	2,168.43	8,820.72		
9540+9560*		0.37	13.12	2.89	2.18	8.88		
9560*+9390		2.02	71.61	15.75	11.92	48.48		
9560*+9536*		175.68	6,227.86	1,370.13	1,036.51	4,216.32		
9560*+9540		0.64	22.69	4.99	3.78	15.36		
6460	Seasonal/ intermittent freshwater lakes	12.97	91.44	115.82	129.7	959.78	1,296.74	99.98
Asbestos mine	-	320.57						
Unvegetated	-	238.68						
Total		**9068**	**301,146.61**	**66,475.78**	**50,224.41**	**204,858.50**		
Carbon stored in plants (tonnes C)			**622,705.30**					**73.18**
†: * refers to priority habitat type included in Annex I of Habitats Directive.								

Based on the matrix outcomes (see Suppl. material 2), the majority of ESs are concentrated at the Troodos peak and the nearby areas (Fig. 4). The same pattern also applies for the evaluation of Cultural Services (Fig. 7). Provisioning (Fig. 5) and Regulation-Maintenance (Fig. 6) services seem to have similar pattern, i.e. the majority of these services concentrate at the centre and western part of the site.

Thirteen out of the 36 ESs received a score above 400, indicating the importance of these services provided by TNFP. These are: a) Mushrooms, herbs, wild berries, b) Wood and resin, c) Timber and d) Hunting (Provisioning Services), e) Controlling or preventing soil loss, f) Stopping landslides and avalanches harming people, g) Protecting people from winds, h) Spreading the seeds of wild plants, i) Providing habitats for wild plants and animals that can be useful to us, j) Ensuring soils form and develop, k) Ensuring the organic matter in our soils is maintained, l) Regulating our global climate and m) Regulating the physical quality of air for people (Regulation & Maintenance Services).

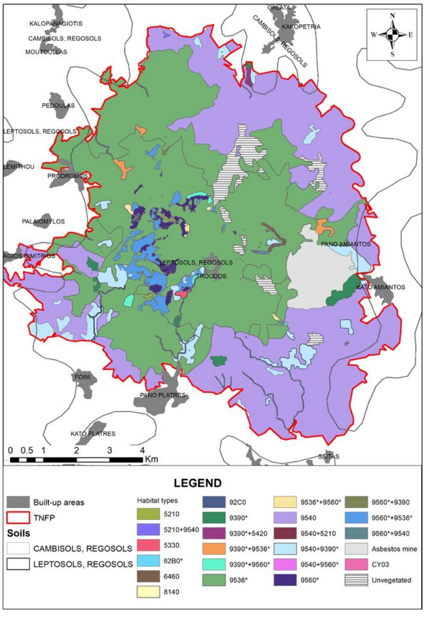

Figure 3.

Annex I habitat types (according to Habitats Directive) at Troodos National Forest Park.

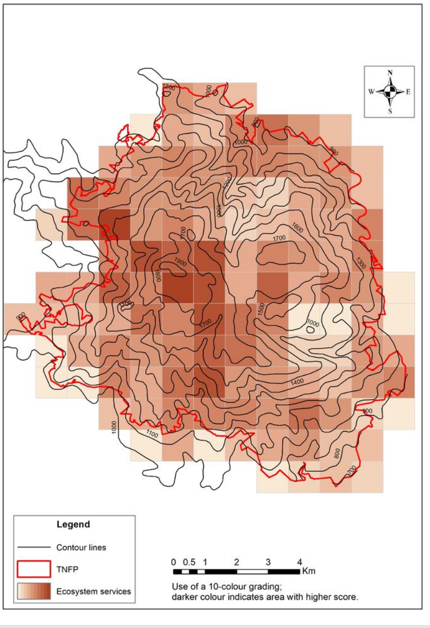

Figure 4.

Concentration of Ecosystem Services at Troodos National Forest Park.

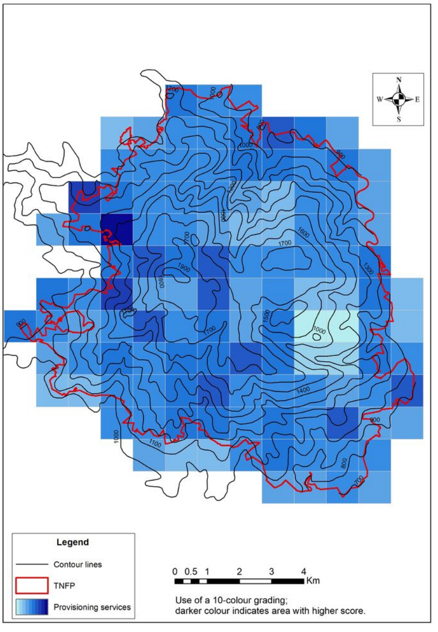

Figure 5.

Concentration of Provisioning Ecosystem Services at Troodos National Forest Park.

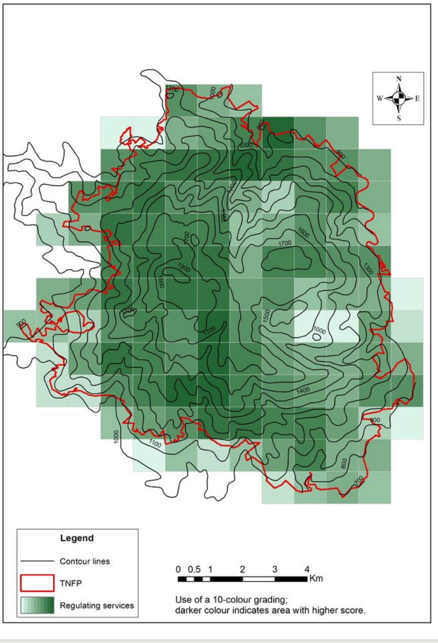

Figure 6.

Concentration of Regulating Ecosystem Services at Troodos National Forest Park.

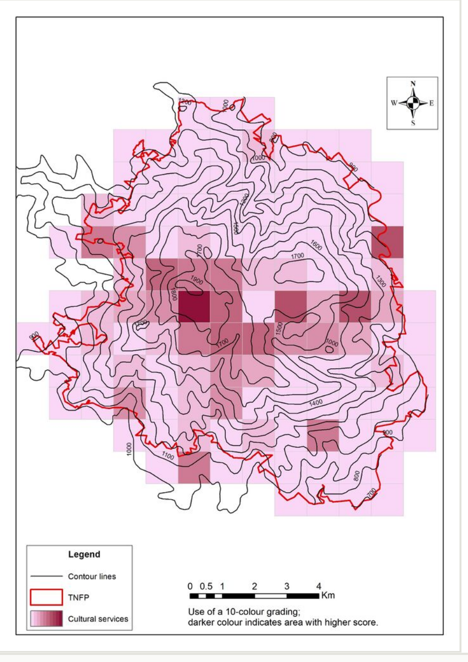

Figure 7.

Concentration of Cultural Ecosystem Services at Troodos National Forest Park.

Ten out of 36 ESs recorded within TNFP occur in all grids (121 grids in total). These are: a) Controlling or preventing soil loss, b) Stopping landslides and avalanches harming people, c) Regulating the flows of water in our environment, d) Ensuring soils form and develop, e) Controlling the chemical quality of freshwater (Regulation & Maintenance Services), f) Observing the habitats of plants and animals ; using nature to de-stress, g) Researching nature, h) Studying nature, i) The beauty of nature and j) Willingness to preserve plants, animals, ecosystems, landscapes for the experience and use of future generations; moral/ ethical perspective or belief (Cultural Services).

Global Climate Regulation

The assessment of GCR revealed that the Total Carbon sequestration is 622,705 t C. This refers to the Carbon stored in the plants, where AGB is 301,147 t C, BGB is 66,476 t C, Litter and Dead wood is 50,224 t C and SOM is 204,858 t C (Table 1).

In addition, methane (CH_4) emissions amount to 0.09 t C_{CH4} y^{-1} as shown in Table 2. The emissions during ice-cover periods are assumed to be zero.

No agricultural activities are carried out within TNFP and nitrogen emissions (N_2O) are considered negligible. ‘Cultivated terrestrial plants grown for nutritional purposes’ mentioned in Suppl. material 1 refer to cultivations outside TNFP, but close to the boundaries of the site. The specific ES is considered to be enabled/provided by TNFP as a consequence of the forest ecosystem and, specifically, the recorded Regulation & Maintenance services.

Table 2.

Methane emissions data and calculations.

Area (ha)	**Ice free period (D)**	**E(CH_4)diff**	**CH_4 emission rate ($t\ CH_4\ y^{-1}$)**	**C lost as CH_4 ($C_{CH4}\ y^{-1}$).**
12.97	205	0.044	0.117	0.088

The Overall Greenhouse gas flux (volume of greenhouse gases absorbed in TNFP), based on GWP_{100}, is 751,151 t CO_2 eq y^{-1} (Table 3).

Table 3.

Overall Greenhouse gas flux in CO_2 equivalents.

Soil Organic Matter (SOM) ($t\ C\ y^{-1}$)	**CO_2 equivalent for SOM ($t\ CO_2\ y^{-1}$)** (a)	**CH_4 ($t\ CH_4\ y^{-1}$)** (at wetland)	**CO_2 equivalent for CH_4 ($t\ CO_2\ y^{-1}$)** (b) (at wetland)	**TOTAL CO_2 ($t\ CO_2\ y^{-1}$)** (a+b)
204,858.50	**751,147.83**	0.117	**3.28**	**751,151.11**

The annual change in carbon stocks in biomass was estimated to be 3,240.09 t C y^{-1}, where the annual decrease in carbon stocks due to biomass loss was estimated to contribute to an annual Carbon (C) loss of 80.82 t C y^{-1}, while the annual gain in biomass was estimated to be 3,320.91 t C y^{-1} (Table 4). The increase of CO_2 stored in the area (by multiplying the above value with 44/12) is 11,880.33 t CO_2 y^{-1}(0.38 t C y^{-1} ha^{-1}).

Table 4.

Annual change in carbon stocks in biomass using annual gain in biomass and decrease in carbon stocks for use as fuelwood, charcoal and roundwood (for the decrease, 2017 data from Cyprus Department of Forests was used).

Annual carbon loss (ΔC_L, $t\ C\ y^{-1}$) (a)		**Annual carbon increase (ΔC_G, $t\ C\ y^{-1}$)** (b)		**Annual carbon change (ΔC_B, $t\ C\ y^{-1}$)** (b-a)
$L_{FUELWOOD}$ ($t\ C\ y^{-1}$) where Fuelwood and charcoal removals are 191.65 m^3	**60.35**	$\Delta C_{G\text{-}BR}$	**46.69**	**3,240.09**
$L_{WOOD\text{-}REMOVALS}$ ($t\ C\ y^{-1}$) where Roundwood removals are 65.02 m^3	**20.47**	$\Delta C_{G\text{-}BR}$ (Quercus spp)	**15.43**	
$L_{DISTURBANCE}$ ($t\ C\ y^{-1}$)	**0**	$\Delta C_{G\text{-}CON}$	**3,258.79**	
80.82		**3,320.91**		

Discussion

The global importance of tropical areas in supplying ecosystem services has been investigated from early studies (e.g. Maass et al. 2005; NAHUELHUAL et al. 2006; Martínez et al. 2009); mountain areas have not been investigated to the same extent, having the majority of work taking place in the last decade (e.g. Alvarez et al. 2014; Tuffery et al. 2021). Essential ecosystem services provided by mountain ecosystems degrade due to various reasons like climate, demographic and economic changes (including deforestation, wildfire and other agents that affect vegetation's ability to remove carbon from the atmosphere), impacting the people living in and outside mountain areas (Ciais et al. 2013; Grêt-Regamey and Weibel 2020).

Mountains represent a quarter of the Earth's surface (Payne et al. 2002), shelter many of the world's principal biomes (Grêt-Regamey et al. 2012; Martín-López et al. 2019) and many ESs are dependent on their development. Mountains represent key regions for preserving biodiversity and functioning ESs, which have further benefits for lower elevation areas (Martín-López et al. 2019; Ramel et al. 2020), where more than 24% of the world's lowland population are projected to critically depend on runoff contributions from mountains by 2050 (Viviroli et al. 2020).

Forests in the European Union (EU) cover about 40% of its area, providing a wide spectrum of invaluable ecosystem services to more than half a billion people. Their ecosystems provide a wide spectrum of services that human societies enjoy and depend upon, that include tangible goods, such as wood and non-wood products, regulating functions, such as soil stabilisation, carbon sequestration and water retention and cultural benefits, such as recreational opportunities and spiritual values (Orsi et al. 2020).

The current work is the first, comprehensive, ESs assessment of a natural forest area in Cyprus. The outcomes of the assessment revealed the importance of TNFP for ESs provision, in addition to being a plant biodiversity hotspot (Medail and Quezel 1997), benefitting both local communities and all Cypriots in general.

Services with higher score (i.e. higher occurrence in grids - see Suppl. material 2) belong mostly in Regulation & Maintenance services, except hunting (Provisioning service). Hunting had the highest score, since TNFP provides the opportunity for regulated hunting in certain periods of the year, in a large part of this Natura 2000 site. The most important Regulation & Maintenance services are considered to be those that are not easily understood and obvious for people, like protecting people from weather phenomena (e.g. wind), regulating global climate, regulating the physical quality of air and providing habitats for wild plants and animals that can be useful to people.

Cultural services are also important for people's well-being, where Recreation activities in the study area are highly associated with nature-based activities. This is the reason for the high number of visitors all year round in the site. Troodos National Forest Park receives around 400,000 visitors each year (Makrominas et al. 2020) (more visitors than any other natural area in Cyprus), both from Cyprus and abroad, who visit TNFP to enjoy the unique beauty of its ecosystems. Controlled visitor movements in specific areas, for example, nature trails, picnic and camping sites, waterfalls, environmental centers etc. are the reason for the concentration of related ESs in specific areas (recorded in low number of grids). However, in this way, uncontrolled visitors' movement, fire events and littering are mediated and the local ecosystems are protected.

Carbon sequestration capacity, especially in protected areas, is important for maintaining biodiversity and ecosystem services (Parrotta et al. 2012; Hicks et al. 2014; Shi et al. 2020); however, the positive relationship between biodiversity and carbon sequestration needs to be further examined (Midgley et al. 2010; Buotte et al. 2019). At TNFP, the largest part of the site is dominated by Evergreen Broadleaf Forests (7799 ha), followed by Mixed Forests (624 ha) and Deciduous Broadleaf Forests (60 ha). The area of each ecosystem (see Fig. 2) corresponds to the carbon stock included in AGB, Dead Wood & Litter and SOM due to the plant species forming these ecosystems. Below Ground Biomass is higher in Evergreen Broadleaf Forests, followed by Mixed forests and Closed Shrublands. Total carbon stock is higher in Evergreen Broadleaf Forests, followed by Mixed Forests. This agrees with the results of Canedoli et al. (2020), with the main difference being the total carbon stock at Grasslands, which can be attributed to both the small area and the sparse vegetation at TNFP.

The present study mapped the ESs of TNFP using a coarse grid resolution of 1 km x 1 km. More detailed data could be recorded using a 100 m x 100 m grid within this area; however, due to limitations regarding human resources, time and budgeting, the authors implemented this spatial resolution for mapping ESs in order to rapidly provide possible tangible outcomes to an information and awareness LIFE project (implemented in Cyprus between 2017 and 2020). The project (iLIFE-TROODOS) aimed to increase public awareness on the natural values of TNFP for which it was included in the Natura 2000 network and the ESs it provides. The project utilised the main outcomes of the current study to develop key messages for the communication campaign, reaching 94% Cypriots of the population of Cyprus (750,000 people) and 27% of tourists visiting Cyprus, thus managing to achieve an increase in the level of awareness on most of the target groups set by the project (Andreou and Mazaraki 2020).

The coordinating beneficiary and End User of the iLIFE-TROODOS project is the DF (as well as the competent authority responsible for the management of TNFP). The DF received the outcomes of this study (and the relevant reports of iLIFE-TROODOS project) for future utilisation. The detailed maps for each ES provide the DF with considerable data to apply (where needed) targeted conservation or protection measures for environmentally sensitive areas or to control visitor movements. Moreover, the key messages of the iLIFE-TROODOS during its awareness campaign (expected to be utilised more from the competent authority in future awareness campaigns), regarding the importance of the ESs of TNFP was highly effective and this is also evident from the three-year monitoring and implementation of the "Mitigation plan for visitors' pressures" (Tziortzi et al. 2019).

Compared to another Mediterranean area, i.e. Kizildag Planning Unit in Turkey (Dinc and Vatandaslar 2019), TNFP appears to store more carbon (more than 73 t ha^{-1} of carbon stored, amounting to 622,705 t of C within the area compared to 64.99 t ha^{-1} in Kizildag Planning Unit). This results in the volume of greenhouse gases absorbed in the TNFP to be 11,880.33 t CO_2 eq y^{-1}. Furthermore, the continuous management and protection of the area allows for the annual gain in biomass to outweigh the loss, resulting in the increase of CO_2 stored in the area by 11,880 t CO_2 y^{-1}. More precise calculations of the carbon stored, greenhouse gases absorption and biomass gain and loss can be made with further field information from the area.

Overall, TNFP provides numerous ESs that benefit people living in Cyprus and visitors to the Island. Cypriots and tourists visit the TNFP to enjoy the unique beauty of its ecosystems and interact with nature-based activities. Troodos National Forest Park is important for its Cultural, Provisioning and Regulation-Maintenance services, where the last two categories affect the whole Island and not only the people living in the nearby area.

Conclusions

The current study managed to present the unique environment of TNFP and support the decision for including this area as a Natura 2000 site. Numerous ESs (35 in total) were recorded within this relatively small area (which stores 73.18 t of C ha^{-1} and absorbs 11,880.33 t CO_2 eq y^{-1}), supporting the fact that it is the most important natural area of Cyprus and one of the ten hotspots of the Mediterranean Basin. The mapping of TNFP's ESs provides the competent authority of the Republic of Cyprus with the necessary information to increase awareness with targeted information campaigns (such as the campaign carried out in the period 2017-2020 under the LIFE programme with the acronym 'iLIFE-TROODOS'). Nevertheless, a more detailed mapping (e.g. grid resolution of 100 m x 100 m) of the ESs, as well as increased field data collection (more precise calculations of the carbon stored, greenhouse gases absorption and biomass gain and loss), could provide a better representation of the importance and value of the area's ESs, where the data derived can be used in the campaigns. 'iLIFE-TROODOS' provided the visitors of the area and the general public important information in order to realise that the quality of the experience they receive and their recreational opportunities are provided by nature for free. After all, human well-being derives from habitats and their diversity and relates to regional biodiversity and/or ecosystem functions, thus providing cultural services. Land cover (i.e. habitat) structure and areas with high species diversity appear to be more appealing to people and habitat diversity not only contributes to biodiversity, but also provides cultural ecosystem services (Osawa et al. 2020).

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Supplementary materials

Suppl. material 1: Mapping of Ecosystem Services at Troodos National Forest Park doi

Authors: Kounnamas C., Andreou M.
Data type: Ecosystem services recorded at the site
Brief description: Mapping of Ecosystem Services at Troodos National Forest Park, based on the Common International Classification of Ecosystem Services (CICES 5.1).
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Suppl. material 2: Scoring of Ecosystem Services at Troodos National Forest Park doi

Authors: Kounnamas C., Andreou M.
Data type: Scoring of ecosystem services recorded at the site
Brief description: Scoring of Ecosystem Services at Troodos National Forest Park, based on the Common International Classification of Ecosystem Services (CICES 5.1).
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Suppl. material 3: Maps of Ecosystem Services recorded at Troodos National Forest Park doi

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